The Re-use of Site Data to Inform Business Processes

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Summary

The increased implementation of site data capture technologies invariably results in an increase in data warehousing and database technologies to store captured data. However, restricted use of data beyond the initial application could potentially result in a loss of understanding of site processes. This could in turn lead to poor decision making at production, tactical and strategic levels. Concrete usage data have been collected from two piling processes. These data have been analysed and the results highlighted potential improvements that could be made to existing site management and estimating processes. A cost benefit analysis has been used to support decision making at the strategic level where the identified improvements require capital expenditure.

1 Introduction

Construction site IT has been a well-researched area since the late 1980's, with applications being developed for many tasks, such as: inspection and reporting (Cox et al. 2002; Songer and Rojas, 1996; Liang, 1997); supervision (Alexander, 1997); and materials and personnel management (Baldwin et al. 1994; Escheverry, 1996). This growth in data collection applications has led to an increase in database systems required to store and manage the collected data. However, these are often built around and integrated with a specific data collection application. This effectively limits data to the primary application resulting in a lack of further re-use, because data collected on a process specific basis usually results in:

- an incomplete data set;
- inadequate database structures that do not facilitate data re-use; and
- data remaining at individual business process levels.

Even where well structured and accessible databases are available for sharing throughout the business, analysis and re-use may be limited by factors such as, time, data complexity and lack of defined mechanisms that can extract, process and analyse the data (Soibelman and Kim, 2002)

A key factor in the success of any construction company is the successful delivery of individual projects. Two business processes that have a large bearing on the level of success are estimating and site management. Whilst some data collection applications allow for the improvement of individual processes such as estimating (Kanaan and Vorster, 1998), there still remains the potential to re-use site collected data to inform the company at three distinct levels, operational, tactical and strategic.

Operational Analysis may be used by operational personnel such as project engineers, foremen or project managers to monitor, control and improve individual site processes.

Tactical Cross-contract or process specific analysis can be used for measuring and improving resource efficiency, improving accuracy of estimating, highlighting training requirements or informing decisions on the most appropriate solution for future contracts.

Strategic Driven by senior management operating at the business level, data re-use and analysis may provide information that may lead to competitive advantage or guide investment decisions.

This paper presents an example of site data collection used at Stent Foundations Limited, a major UK piling contractor. Concrete usage data have been collected from two piling processes. These data have been analysed and the results used to highlight potential improvements that could be made to existing site management and estimating processes and contribute to strategic decision-making.

2 Data Acquisition

Two distinct approaches have been made by Stent Foundations in the acquisition of site data for piling works. Manual data capture by the site workforce (Ward et al. 2002), and automated data capture using on-board computers (Scott, 1999).

2.1 Manual Data Capture

Manual data capture is carried out for the Rotary Bored Piling (RBP) process, which is a labour intensive process comprising of four distinct phases: (1) a temporary casing is installed into the ground to support the upper levels of soil; (2) a piling rig drills through and below the casing to the pile toe level; (3) reinforcement cage and concrete are placed into the open bore; (4) the temporary casing is removed.

In order to facilitate data capture, and assist in the control the RBP process the SHERPA (Stent Handheld Electronic Piling Assistant) has been developed comprising of; (1) a site based website for project data; (2) a site based wireless network; and (3) workforce driven data capture utilising tablet computers. A site website, residing on a server in the site office, has been developed for the management and construction of rotary bored piles. The website is accessed by site management staff to manage design data, incoming site data and contract documents, such as timesheets and plant returns.

Construction workers access pile design data located on the server using a standard web browser on a Windows CE tablet computer (Figure 1) and enter as-built data as the pile progresses. SHERPA provides the user with guidance on tolerances, materials and levels for each pile, prompting and alerting users as necessary to potential non-conformances. Data entered includes dimensional information of the pile and details of concrete and steel.

Figure 1.Banksman Operating Tablet Computer

All data resides on a MySQL database located on the site server and is accessed/transferred by the workforce to the site server utilising a battery powered IEEE 802.11b wireless network. The wireless network utilises Wireless Network Cells (WNC) that allow the creation of a portable and flexible wireless networking solution without the need for a wired backbone (Figure 2), commonly seen in many wireless workplaces (Ward, et al. 2003).

Figure 2. Battery Powered WNC Installed on Piling Rig

2.2 Automated Data Capture

SIRIS (Stent Integrated Rig instrumentation System) is an automated piling rig instrumentation system used in the construction of Continuous Flight Auger (CFA) piles (Figure 3). Due to the ‘hidden’ nature of a CFA pile it is practically impossible to control the process by observation alone, consequently on-board instrumentation is used to ensure the production of a conforming pile.

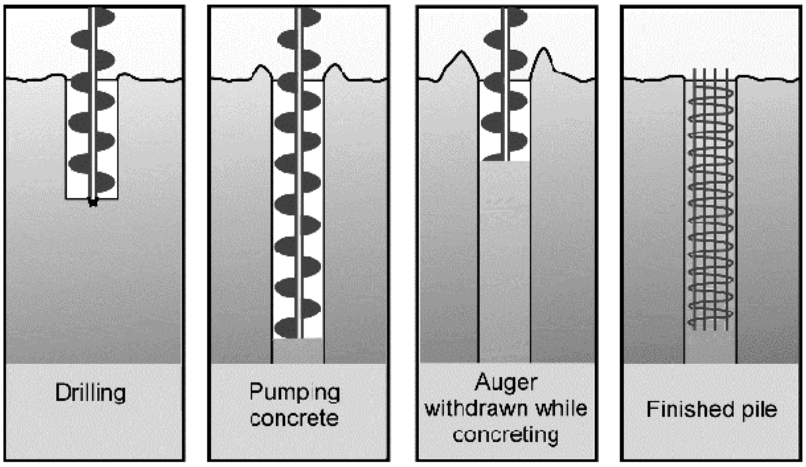

Figure 3. The CFA Piling Process.

The whole process is controlled by the rig driver who is guided by an on-board touch screen computer (Figure 4). On-board sensors and meters are used to record, auger depth, concrete pressure, concrete volume and torque which are relayed to the on-board computer and presented to the rig-driver via a graphical interface.

Figure 4. SIRIS Computer Mounted in Piling Rig Cab

All data collected by SIRIS, is retained on the on-board computer in paradox tables and is automatically transferred to the head-office via Global Systems for Mobile Communications (GSM) dial-up connection at the end of each working shift. A text messaging service has also been established, allowing any staff to dial-up the rig from their mobile phone and request a status report via text message that contains the following summary:

- current operational status of the rig, drilling, concreting or delayed;
- number of piles completed in the shift;
- average overbreak for the shift; and
- total delay time.

3 Integration of Site Data

Both SHERPA and SIRIS have been targeted at improving production control, with data from these systems entering the business at the operational level. Therefore, the potential for further re-use of data at the tactical and strategic levels will be driven from data analysis conducted at this level (Figure 5).

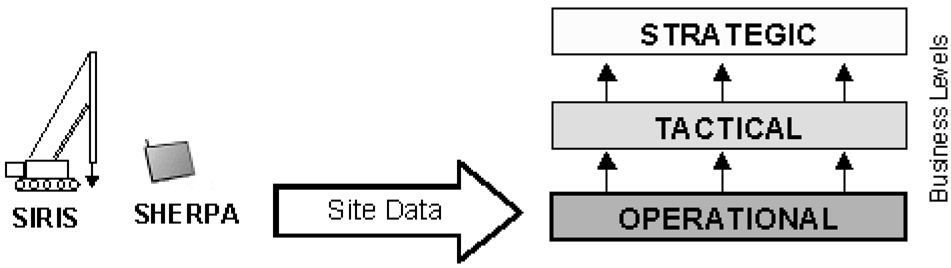

Figure 5. Integration of Site Data within the Business

3.1 Operational Level

Currently, site data re-use at the operational level, is based on known practices and experiences of individual staff operating at this level. Such practices are simplified and often have limited re-use of data which can be attributed to historical factors such as; (1) the paucity of data; and (2) time limitations for processing and analysis.

This potentially places both SHERPA and SIRIS data at risk from under-utilisation, with staff requesting data to match existing management and reporting processes.

3.2 Tactical Level

The use of site data at a tactical level for business is extremely limited. Although paper-based site data may be available for re-use this is not integrated within the tactical level due to the following:

- Unwieldy format; and
- Inconsistent or incomplete data;

Tactical decision-making is often based on personal experience and knowledge at individual business processes such as estimating. Such knowledge may be based on out-of-date information that may lead to inconsistent decisions or inaccurate assumptions. Where data is re-used this tends to be in the form of more accessible data from costing processes. This leads to the creation of information and knowledge voids, particularly with respect to production knowledge at this level. It is therefore necessary to analyse site data to provide knowledge at this level informing estimators and middle managers of what happens at the production level.

3.3 Strategic Level

Due to the low profit margins within construction there is a need to justify capital expenditure at all levels, this is no truer than in Information Technology that is based on indirect benefits, which may be difficult to measure (Andresen et al. 2000). In order to justify the implementation of IT systems such as SHERPA and SIRIS, analysis of data from the systems can be carried out to justify expenditure on any potential process improvements.

4 Data Analysis

The piling industry utilises two main materials, ready mixed concrete and reinforcement. Current expenditure on concrete within the company is approximately £15 million per annum which equates to approximately 30% of company turnover, therefore analysis of concrete usage and waste has the potential to impact on company profitability. Prior to the use of SIRIS and SHERPA, such analysis has been limited, however, there now exists the opportunity to undertake data analysis from the CFA and RBP processes to generate further understanding and guide the company.

Two main factors affect the use of concrete within the CFA and RBP processes, these are overbreak and over boring. Overbreak is the percentage of concrete used in relation to the theoretical pile volume and is used by estimators and site managers for both financial and quality purposes. Over boring is the additional bored length of pile over the designed length. Table 1 shows the relationship between these factors, business processes and construction methods. This shows that overberak is the main measure currently used at both the operational level (site management) and tactical levels (estimating). However, over boring is not currently considered as a control measure at any level of the company, which may be due to the following factors; (1) overbreak is considered a measure of quality, whereas over boring is not; (2) lack of available data and analysis; (3) site level emphasis on production output.

The collection and analysis of site data via SHERPA and SIRIS potentially allows for improved understanding of overbreak and over boring, leading to possible improvements in site processes and estimating, and justifying investment.

Factor	Business Levels			Construction Method	
	Operational	Tactical	Strategic	CFA	RBP
Overbreak	O	O	Not used	O	O
Over boring	Not used	Not used	Not used	Not used	O

Table1. The Use of Concrete Supply Factors in Business Processes and Construction Methods

4.1 Concrete Overbreak

When preparing tender documents, estimators include an additional overbreak volume for each pile, based on empirical measurements. This is based on the experience of the estimator with soil type being the most widely used factor. Inadequate site investigations may require the estimator to look up previous contract details from paper-based records to further inform the overbreak calculation.

Site managers use overbreak to calculate the soundness of each pile, by comparing the volume of concrete placed against the theoretical volume of the pile based on the design toe level. A large underbreak may suggest necking of the pile and a reduction in diameter placing the integrity of the pile at risk, whereas a large overbreak has financial implications for the company through over use of concrete. A simple calculation is often carried out by site managers based on design data and collation of concrete delivery tickets to provide an overbreak percentage for each pile.

	CFA	RBP
Number of piles	6,473	1,214
Period (weeks)	52	10
Number of rigs	8	6
Volume of concrete placed (m3)	27,000	11,000
Average overbreak (%)	23.5	11.5
Median overbreak (%)	18.2	9.6
Estimated overbreak (%)	15 - 20	15

Table 2. Summary of Overbreak data used in Analysis

Table 2 shows a summary of the data collected from SIRIS and SHERPA for the analysis of concrete overbreak. This includes the total number of piles in the data set, the period over which the data has been collected, number of rigs collecting the data and the total volume of concrete placed in the period.

4.1.1 CFA Piling

Concrete overbreak in CFA piling is estimated between 15% - 20%, which can be attributed to the ‘hidden’ nature of the CFA process, inability to inspect the bore and placing the concrete under pressure. Concrete overbreak can be caused by too high a concrete pressure below the auger, resulting in either an expansion of the pile bore or concrete rising up the auger flight. At the start of each contract, the target overbreak percentage provided by the estimate is entered into the SIRIS system. Concrete is pumped into the pile bore below the auger, as the auger is withdrawn, the concrete replaces the void left by the auger. The rig driver utilises concrete pressure monitors and overbreak indicators to manually extract the auger at a steady rate to produce a conforming pile.

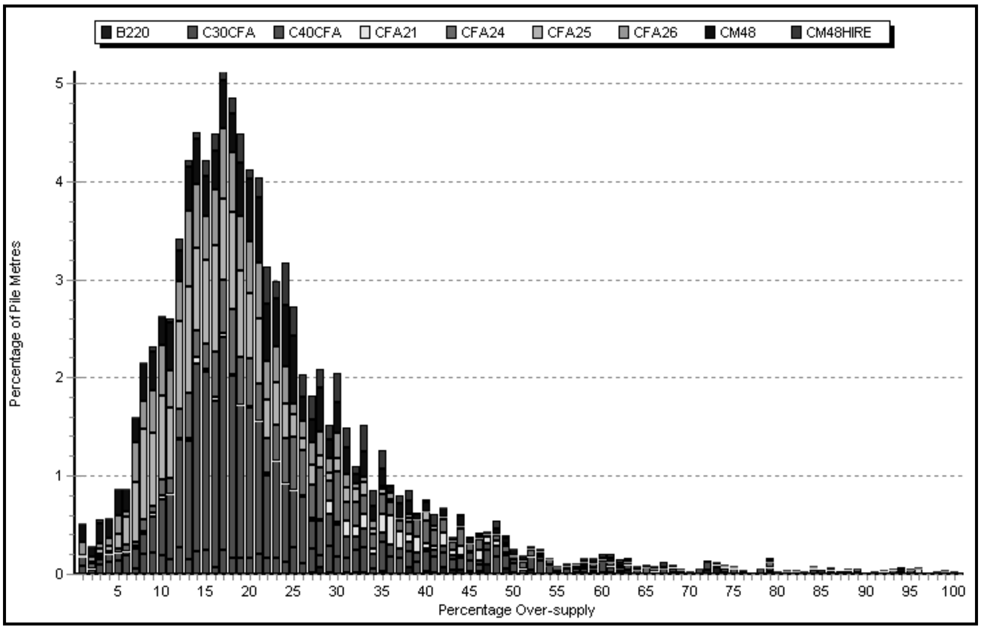

Figure 6. CFA Overbreak Distribution

Figure 6 shows a distribution of the overbreak for all CFA piles constructed for one year's production in similar soil types. The dataset has an average overbreak of 23.5% and a median of 18.2%. The skewed distribution can be attributed to the use of a target overbreak and the tendency of the rig driver to over achieve the target. This essentially means that the drivers are adding a factor of safety to ensure a sound pile, a human factor, which is unlikely to be totally managed out through improved training or procedures. In order to counter this, an automatic auger extraction system can be implemented at a cost of £45,000; however, such investment has been traditionally hard to justify due to lack of analysis.

To justify expenditure at the strategic level, a cost benefit analysis was carried out (Table 3) which suggests a payback period for auto-extraction in less than 6 months.

Concrete Usage (m^3)	27,000
Overbreak volume at 23.5% (m^3) **(X)**	6,345
Overbreak volume at 19% (m^3) **(Y)**	5,130
Volume of concrete saved **(X – Y)**	1,215
Saving per annum (at £60/m^3)	£103,275
Cost of implementation (£)	£45,000

Table 3. Cost Analysis for Implementing Automatic Auger Extraction in CFA Process

4.1.2 Rotary Bored Piling

The overbreak data used for RBP is based on a single site, with predominantly clay soil. The estimated overbreak for the site was 15%. Currently site managers can calculate the overbreak percentage for each pile through the utilisation of design data that is often presented in spreadsheet format. However it is more difficult to analyse such data related to the construction process such as, the rig, driver, and crew or as constructed depths. This is because such data is located on many different documents requiring much effort on the part of the site manager.

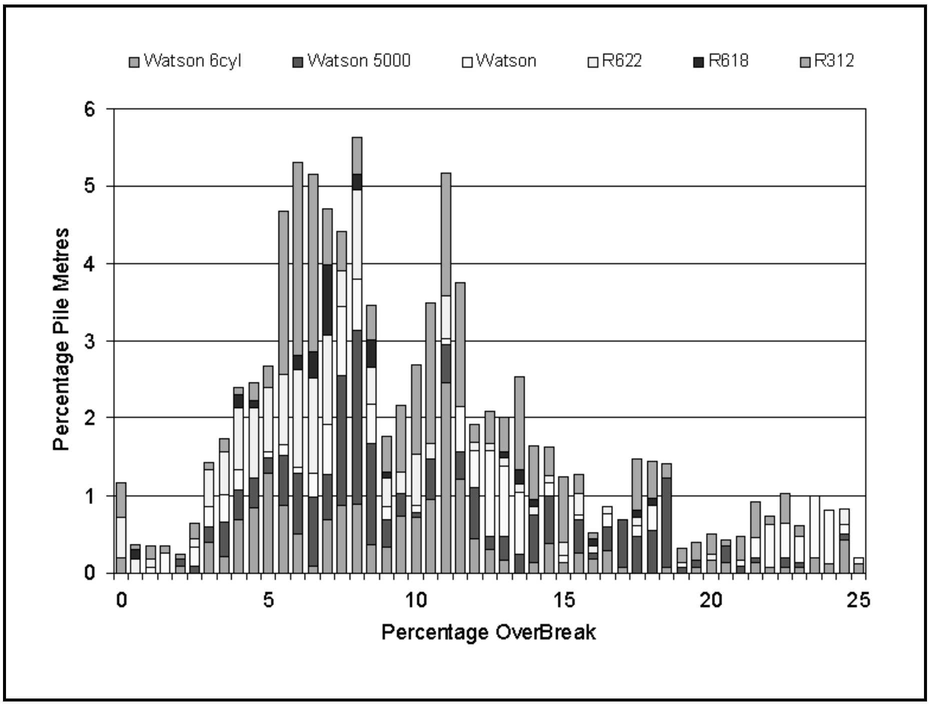

Figure 7. RBP Overbreak Distribution for Rigs

Figure 7, shows the distribution of overbreak for RBP piling for six rigs, which shows an average overbreak of 11.5% with a median of 9.6%. This distribution indicates a more random process than that of CFA. The reasons for the variation can be attributed to a number of factors including; (1) inaccurate measurement of actual concrete volume in the pile; (2) manual measurement of pile depths; and (3) lack of automation and guidance mechanisms.

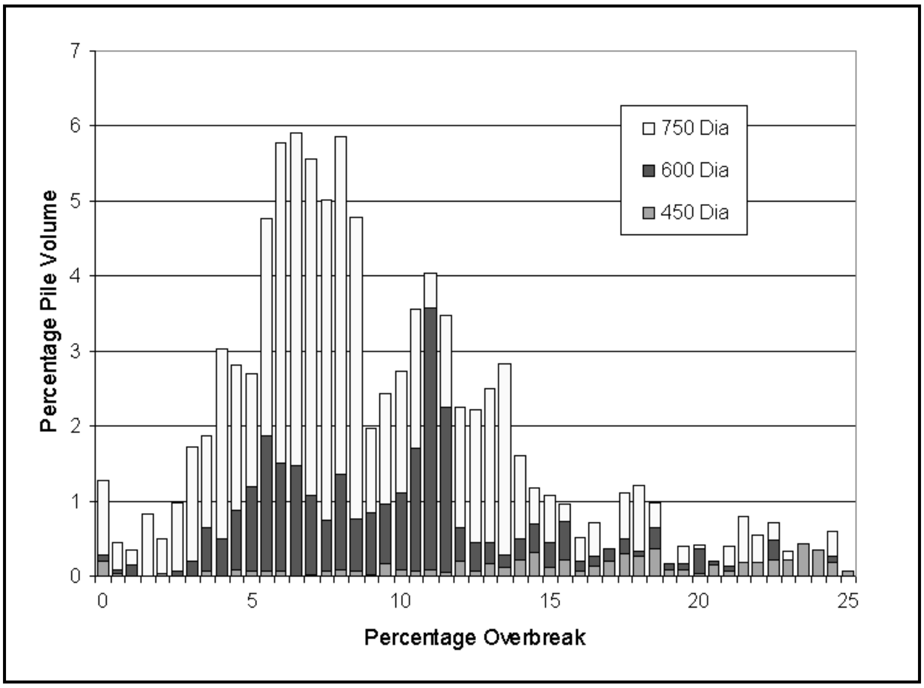

Figure 8. RBP Overbreak Distribution for Diameter

The size of the pile being excavated would be expected to have an impact on the percentage of overbreak. This is confirmed in Figure 8, which shows the distribution of overbreak with respect to 750mm, 600mm and 450mm diameter piles with average overbreaks of 9%, 7%

and 17% respectively. The similarity between 750mm and 600mm piles and the large variation to 450mm diameter piles is indicative of the casing installation process used, with vibration equipment used on the larger diameters whilst the 450mm piles are pre-bored which causes large overbreaks around the top of the pile.

The average site overbreak compares favourably to the estimate of 15%, suggesting a net gain for the site from the over-estimation of concrete. However, it should be noted that the use of vibrating equipment was found not to be included in the original estimate. When this is taken into account the net gain becomes a loss (Table 4). This suggests that additional analysis should be undertaken to provide estimators with a cost benefit of the utilisation of vibrating equipment for the installation of pile casings, which could also take into consideration any increased productivity from improved casing installation times.

Concrete Usage (m^3)	11,000
Overbreak volume at 15% (m^3) **(X)**	1,650
Overbreak volume at 11.5% (m^3) **(Y)**	1,265
Volume saved **(X – Y)**	385
Saving (at £85/m^3)	£32,725
Cost of vibration equipment (£)	£40,000
Net Gain	-£6,750

Table 4. Net Gain from Reduced Site Overbreak in RBP Process

4.2 Pile Over boring

Over boring is specific to the RBP process and is caused by the rig driver digging the pile deeper than necessary. The length of each auger varies with pile diameter but is typically in the range of 1.5 – 3m, requiring the auger to be dropped into the bore a number of times to reach the required toe level. After each dig the depth is measured by the banksman using a tape, whilst the driver spins-off the auger to remove the excavated soil. Payment for pile production is based on the design toe level, therefore the cost for boring and filling additional depth with concrete is borne by the piling contractor. To date, analysis of over boring has not been undertaken due to restraints in collating data.

There are many factors that affect the ability to reach the target depth of the pile such as; (1) the accuracy of taping; and (2) the ability of driver to control the auger speed and rotation. Figure 9 shows the distribution of over boring in the RBP process with an average overbore of 1.26% and a mean of 0.97% of pile depth. The total overbore length for the sample is 332m with a total overbore volume of 117 m^3. The quantity of over boring not only incurs costs from additional concrete but also from the disposal of spoil, whilst the additional length of boring effectively equates to a loss in productivity.

The skewed distribution is indicative of the tendency to over bore the pile and is comparable to that of pile overbreak in CFA, suggesting that the use of a target is an influencing factor in both instances.

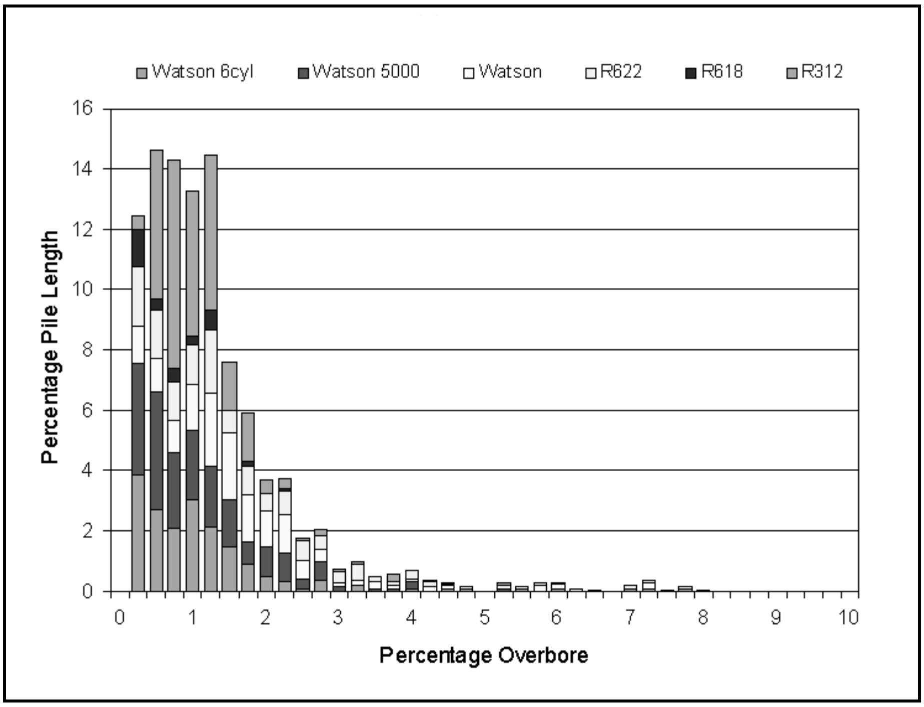

Figure 9. Distribution of over boring in RBP Process

To improve control of over boring in the RBP process, two measures can be implemented; (1) changes in bonus schemes to reflect quality of workmanship rather than productivity; and (2) the implementation of auger depth gauges on the rigs.

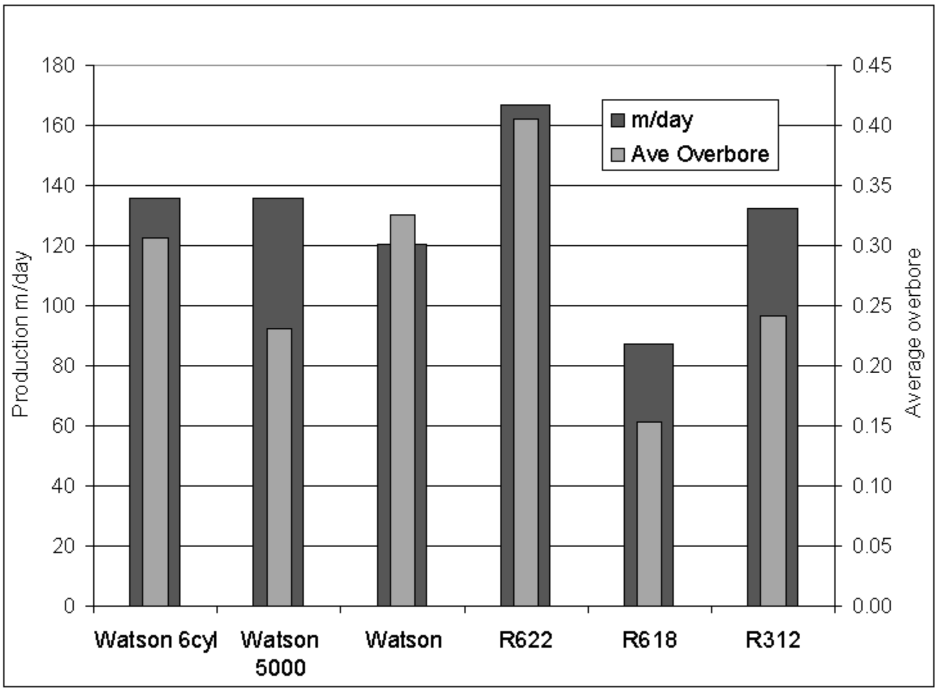

Figure 10. Relationship Between Over boring and Productivity

Bonus schemes for the site are currently based on the productivity of each rig, based on the design length of piles completed, with overbore not included in the calculation of the bonus. Analysis of the average overbore for each rig versus productivitvity (Figure 10) shows good correlation between productivity and over boring at 0.82. This effectively costs the company double, as they are paying bonuses based on increased productivity whilst at the same time paying for the disposal and filling of the overbore for the faster rigs. Bonus schemes are currently being revised within the company to reflect workmanship and quality. However, as over boring is not currently considered to be poor workmanship, this would require a change in company policy directed from the strategic level.

The potential for reduction in waste due to reduced overbore was discussed with rig drivers and foreman, who suggested that any over boring target should be based on the minimum depth that can practically be excavated in a single spin of the auger, which is 0.2m. Assuming that this average could be met, this would reduce the total overbore volume for the dataset to be 80m^3, resulting in a potential saving of 37m^3.

The adoption of auger depth gauges was considered a more suitable solution, as drivers would be able to see how deep the auger was so that a final dig could achieve the toe level. After discussion it was decided that a figure of 0.15m would be suitable for an average overbore based on the use of depth gauges. The cost of implementation of depth gauges across the fleet would be in the region of £100,000, however such expenditure has been difficult to justify.

Table 5 shows the volume of concrete to be saved from the site for the analysed dataset by reducing the average over boring to 0.150m. The saving of £85/m^3 is inclusive of concrete costs and disposal of additional soil. When applied to the whole company, the potential annual saving would be in the region of £111,000 suggesting a payback period of just less than one year.

	Site Dataset	**Company**
Concrete Usage (m3)	11,000	250,000
Total Overbore Volume (m^3) **(X)**	117	2,667
Target Volume at 0.15m **(Y)**	60	1,361
Volume saved **(X – Y)**	57	1,306
Saving (at £85/m3)	£4,845	£111,010
Cost of implementation £		£100,000

Table 5. Cost Analysis for Implementing Depth Gauges

4.3 Conclusions

Data from automated and manual site systems for two piling processes were analysed with respect to concrete waste, in terms of overbreak and over boring.

Overbreak is the main measure of quality used by the company and is utilised by estimating and site management processes. Overbreak reductions within the CFA process can be achieved through additional automation, which will in turn improve estimating, whilst the RBP process would benefit from more informative estimating systems based on construction methods and productivity.

Over boring is specific to the RBP process and has been shown to have a direct correlation with productivity. Currently over boring is not seen as an indication of poor workmanship, nor is it regularly monitored, however, analysis shows that effective control of over boring can potentially save the company in excess of £100,000 per annum. Two mechanisms are proposed for this; (1) changes to the bonus scheme, requiring a change in company policy; and (2) the installation of auger depth gauges.

Where investment in new equipment has been identified, cost benefit analysis has been conducted which shows payback periods as little as 6 months.

5 Acknowledgements

The authors acknowledge the support and funding provided by Stent Foundations and the Engineering and Physical Research Council (EPRSC) for this work.

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